R E P O R T R E S U M E S

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TEACHING THE FUNDAMENTALS OF ORTHOGONAL PROJECTION, A STUDY IN THE FILM PRESENTATION OF THE THOUGHT MODEL METHOD.

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SIX FILMS WERE DEVELOPED TO TEACH VISUALIZATION IN THREE DIMENSIONS FOR ENGINEERING GRAPHICS OR DESCRIPTIVE GEOMETRY COURSES. THE FILMS UTILIZED A "THOUGHT MODEL METHOD" WHICH HAD BEEN USED FOR OVER A DECADE BY THE INVESTIGATOR. THE METHOD CONSISTED OF TRACING IN THE AIR AND DESCRIBING RELATED POINTS, LINES, PLANES, AND SURFACES BY THE USE OF THE HANDS. THIS CONSTRUCTION OF IMAGINARY FIGURES WAS ACCOMPANIED BY VERBAL DESCRIPTION, AND THE ORTHOGONAL REPRESENTATION OF THESE FIGURES WAS MADE ON THE BLACKBOARD. THE TWO-DIMENSIONAL REPRESENTATION WAS MADE ONLY AFTER THE STUDENT HAD THE EXPERIENCE OF SEEING AND MANIPULATING THE VISUALIZED THREE-DIMENSIONAL PROBLEM. THE FIRST FILM WAS SHOWN ONLY TO TEACHERS TO FAMILIARIZE THEM WITH THE METHOD. USE OF THE REMAINING FIVE FILMS WAS COMPARED TO LIVE USE OF THE METHOD AND TO CONVENTIONAL INSTRUCTION IN A STUDY INVOLVING 358 COLLEGE STUDENTS TAKING DESCRIPTIVE GEOMETRY. IT WAS FOUND THAT THE THOUGHT MODEL METHOD COULD BE LEARNED AND USED EFFECTIVELY BY TEACHERS OF ENGINEERING GRAPHICS TO BRING ABOUT IMPROVEMENT IN CLASSROOM PERFORMANCE. (JM)

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TEACHING THE FUNDAMENTALS OF ORTHOGONAL PROJECTION

A Study in the Film Presentation of the Thought Model Method

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Prefatory Note:

Two problems are approached simultaneously in this study: (1) the question of whether the Thought Model Method of teaching the fundamentals of orthogonal projection can be used effectively by teachers other than the originator of the method; and (2) whether this method can be learned through the use of films. Given substantial financial resources the attack on these two problems could be divided into separate research efforts. Under other circumstances it might be well to do this. In this case it was felt that certain practical considerations were of overriding importance. Present and future demands for technically trained personnel make it imperative that optimal teaching methods be used in engineering colleges. Once such teaching methods have been identified it is essential that optimal methods of communicating this knowledge to engineering educators should be used. The present study, exploratory in nature, represents an attack on both of these problems.

Cover Photos:

Front cover left - A point in space
Front cover right - A line in space

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"THOUGHT MODEL" RESEARCH PROJECT

Introduction

Engineering as a profession is concerned primarily with design. In fact, the core of engineering is design which, in the broadest sense, includes circuits, machines, structures, processes, and combinations of these components into systems and plants. The professional engineer must be capable of predicting the performance and cost of the components, systems, and plants to meet specified requirements. We must not overlook the fact that the theoretical scientist is primarily concerned with the discovery of new knowledge and the development of new scientific principles, whereas the engineer is concerned with the implementation of these principles. The professional engineer deals with the applications of science, tempered by judgment based on experience, to the solution of real engineering problems.

Designing is a conceptual process which is done largely in the mind, and the making of sketches is a recording process, a reliable memory system, which the engineer uses for self-communication to help him "think-through" the various aspects of his project. Graphics is an integral part of the conceptual phase because, more often than not, the making of a simple sketch to express a design conception does of itself suggest further ideas of a conceptual nature. Engineers who have developed their ability to visualize geometrical and physical configurations and to "think graphically" have a decided advantage in creating a physical means of achieving an objective.

The student who undertakes preparation for the exciting and stimulating profession of engineering must have adequate education in

graphics. This means not only facility in freehand sketching, but also thorough knowledge of (a) the fundamental principles of orthogonal projection and experience in the application of these principles to the solution of space problems that arise in both engineering and science; (b) knowledge and use of graphical solutions and methods of computation; and (c) the development of capability to cope with the "many-solutions" type of problems that are so characteristic of engineering.

It is of the utmost importance that engineering students develop the power to visualize and to think in three dimensions -- to think graphically. Not only is this ability to visualize (imagineering) essential to conceptual design but also in the conception of force systems; crystalline structure of matter; time-space relationships; chemical and biological systems; and in the formulation of mathematical models.

A large majority of engineering students can develop effective skill in visualization through well-taught courses in solid geometry and descriptive geometry. Unfortunately, in most cases, solid geometry is no longer required for admission to engineering schools. Descriptive geometry - actually the fundamental principles of orthogonal projection and their application to the solution of space problems - is taught, in many schools, with the aid of pictorials, models, slides, films, and blackboard demonstrations. In many instances, students learn "how" to solve problems dealing with points, lines, planes, and surfaces - often by rote - and fail fully to comprehend the use of the fundamental principles in solving space problems that require the "thinking-through" process of visualization and analysis. Models, pictures, etc., can be no more than an attempt

to show the student what he should do mentally. These aids do not give him adequate practice in developing his mental capacity to formulate, hold and manipulate a three-dimensional problem which can be analyzed and then recorded consistent with the fundamental principles of orthogonal projection. A method has been developed, however, which does give the beginning student practice in developing such skills. This is the Thought Model method which has been used by the investigator, for over a decade, in teaching engineering graphics at the University of California.

The Thought Model Method

The method consists of tracing and describing related points, lines, planes and surfaces, in the air, by use of the hands. This construction of imaginary figures is accompanied by verbal description, and the orthogonal representation of these figures is made on the blackboard (and later by the student at his drawing board). But the two dimensional representation is only made after the student has the experience of "seeing" and "manipulating" the visualized three dimensional problem. In this way it is possible to create geometric space relations which are so fully visualized that the students can come forward and add items, describe elements, analyze and solve problems -- employing the imaginary figure.

Students with high aptitude for comprehension of spatial relationships undoubtedly accomplish this automatically regardless of the method used to teach engineering graphics. However, when the Thought Model method is used by the instructor at the beginning of the course it provides a shared experience in visualizing an imaginary figure for all members of the class. This greatly facilitates communication among the students who can now discuss imaginary fig-

ures with confidence.

On the other hand, students of descriptive geometry trained conventionally often spend a great deal of time working with two dimensional representations or projections until they suddenly "see" what the problem is. This, of course, is the familiar "Aha!" experience described by psychologists. In one sense the Thought Model method can be described as a means of providing the beginning student with the "Aha!" experience at the very outset of his engineering education -- providing it in such a natural manner that the student never imagines that engineering graphics could consist of anything more difficult. With this confidence in his ability to visualize a problem the student is then prepared to advance to ever more complex problems requiring visualization and employ graphic techniques to problems not ordinarily thought to be susceptible to such methods.

The method is used currently by a small number of engineering teachers and is applied to a limited number of engineering problems. This is largely due to the inadequate number of teachers who are skilled in the manipulations needed to create a live and clear imaginary model. It is the investigator's belief that widespread use of the Thought Model method would significantly improve the synthesis and analysis abilities of engineering and science students and would probably have important applications in other disciplines as well.

Objectives of This Study

This study attempts to answer a number of questions related to the general question: Can this method, developed over a number of years and used effectively by one instructor, be learned and effec-

tively used by others? Specifically, answers to the following questions were sought:

1. Can the method be learned and used effectively by other teachers?

2. Can the method be used effectively by teachers who have learned it from films, ie. are the films effective in the "teaching of teachers"?

3. Can the film be used to teach students a range of concepts successfully? In other words, is a film of a teacher experienced in the use of the method an effective device in the teaching of students?

Procedures

Six 16mm sound films approximately 25 minutes in length were prepared in cooperation with the University of California Television Office. These films picture the investigator in a simulated classroom situation presenting basic principles of othogonal projection and the solution of problems by the Thought-Model method. These films were recorded on video tape in a television recorder and then transferred to 16mm film for distribution purposes. All of these films were reviewed by instructors taking part in this study before they used them in their classrooms. The films dealt with the following subjects:

Film A - An introductory film shown only to teachers to familiarize them with the method

Film B - An explanation of the two basic principles of orthogonal projection:

1. In a two-dimensional representation the orthogonal views of a point upon two mutually perpendicular planes lie on a line which is perpendicular to the line of intersection of the planes.

2. When two planes are perpendicular to a third plane, the distance that a point is from this third plane will be seen twice, once in each of the views upon the other two planes.

This film has a short "trailer" which briefly introduces four basic problems dealt with in subsequent films.

Film C - Finding the true length of a line segment (3 methods)

Film D - Finding the point view of a line and the edge view of a plane

Film E - Finding the true shape of a plane surface. This film has a "trailer" which introduces four distance problems and three angle problems

Film F - The problem of finding the distance between skew lines is fully analyzed and solved. The other angle and distance problems introduced in Film E are analyzed. Additional advanced problems are introduced in a "trailer".

In each of these films the lecturer appears exactly as he would in the classroom situation. The only devices used are the Thought Model, blackboard, and chalk.

Six tests were prepared (see Appendix A) to be given in connection with the films. Teachers of descriptive geometry at four neighboring schools were invited to use the Thought Model method in their classrooms. A total of 12 instructors teaching 20 class sections participated in the project. Before adopting the method in their classrooms, the instructors were brought together for a morning session to view portions of the films and raise questions with the investigator. The filmed material and tests were used in the first five class meetings of the beginning course in Engineering Graphics or Descriptive Geometry.

Three teaching procedures were outlined and the instructors chose voluntarily the method (or methods) to be used in their class-

rooms. The three methods were as follows:

I. Thought Model - Live. In this case the students do not see the film. The instructor views all the films and covers the same material in his classroom emulating the film lecturer as closely as possible. The lecturer answers questions and a test is given at the end of each period.

II. Thought-Model - Film. In this case the students view the films in successive class periods. The instructor answers questions for a 20 minute period at the end of each film at which time the appropriate test is given.

III. Conventional. In this case the instructor used whatever method he normally uses in covering the material the student has to know in order to solve the test problems.

(Hereafter these methods will be referred to as "Live", "Film" and "Conventional").

Instructions to instructors were as follows:

> "There are five films which the students will see (films B,C, D,E,F). Films B and E have 'trailers' which follow the main body of the film and which are separated by several feet of blank film. When this break occurs the projectionist should stop the film.
>
> "Approximately one film per class period should be shown and the corresponding test given to the students. If time permits it will be all right to proceed with the next film after the students have completed the test, providing that all sections proceed at essentially the same rate. The important thing is to make sure that all sections cover the same basic material as covered in each film regardless of teaching method, and that tests are given at the right time. The timing of the tests in the control sections should be determined by the time of test administration in the sections viewing the film. The schedule for films and tests is as follows:
>
> 1. Show film "B" up to the trailer
>
> Stop film. Allow 20 minute question period
> Give Test #1 on the two basic principles
> Show remaining portion of film "B"

2. Show film "C". Allow 20 minute question period
   Give Test #2 on true length of a line segment

3. Show film "D". Allow 20 minute question period
   Give Tests #3 and #4 on point view of a line
   and edge view of a plane.

4. Show film "E" up to the trailer
   Stop film. Allow 20 minute question period
   Give Test #5 on true shape of a surface
   Show remaining portion of film "E"

5. Show film "F". Allow 20 minute question period
   Give Test #6 on angle and distance problems

"The success of this experiment depends largely on having all instructors understand the content of the films so that the material presented in sections which do not see the films will be basically the same as that presented in the film. Remember, all students will be given the same tests -- they should all have an equal opportunity, by whatever method used, to gain a comprehension of the material on which they will be tested."

Grading instructions to assure standard practice in all classrooms were also distributed. (See Appendix A)

Results

Table I shows the number of class sections, the number of students in each section and the class means for each instructor. In analyzing the results the mean score of each student on the tests he took was calculated. The class mean was calculated from these individual means. Also, the means for each method and school were calculated from the mean scores of each individual. In other words, the total number of points possible on the six tests was 600, but the mean of these test scores rather than the total raw scores was used in subsequent calculations. This made it possible to include the scores of students who did not take all of the tests, however, only scores of those students who completed at least 5 of the 6 tests are included in this analysis. Table II gives the mean scores for each school and method. Table III compares the three methods

SCHOOL | METHOD

	LIVE			FILM			CONVENTIONAL		
	Inst'r.	no. of students	class mean	Inst'r.	no. of students	class mean	Inst'r.	no. of students	class mean
Diablo Valley Junior College				A B	20 9	43.47 40.52	A	17	48.92
College of San Mateo				C	20	48.37	C	15	47.59
City College of San Francisco	D E F	17 25 12	51.96 50.17 54.72	D D E	23 22 23	45.34 39.49 56.10	D G	17 22	45.47 59.58
San Jose State College	H H I	16 14 21	74.80 79.65 56.29	J K L	22 13 12	70.38 69.81 71.57	J	18	67.25
Totals		105			164			89	

Table I. Mean Score by Class Section

SCHOOL	METHOD					
	LIVE		FILM		CONVENTIONAL	
	no. of students	mean	no. of students	mean	no. of students	mean
Diablo Valley Junior College			29	42.55	17	48.92
College of San Mateo			20	48.37	15	47.59
City College of San Francisco	54	51.74	68	46.64	39	53.41
San Jose State College	51	68.51	47	70.53	18	67.25
Totals	105	59.89	164	53.06	89	54.69

Table II. Mean Score by School

Methods Compared	Mean	No. of Students	t	Significance Level
Live Film	59.89 53.06	105 164	2.25	$p < .01$
Live Conventional	59.89 54.69	105 89	1.36	$p < .05$
Conventional Film	54.69 53.06	89 164	.52	not significant

Table III. Comparison of Teaching Methods

	No. of students	Class mean
Investigator (live)	13	80.76
Investigator (film)	15	69.14

Table IV. Investigator's Classes at University of California

in pairs by means of the t test.

Since this study is concerned with the effect of each method and the film, the test results of students at the University of California, where the investigator taught one section, are not included in the analysis. Table IV, however, gives a comparison of the investigator's class and another section at the University which viewed the film.

Discussion

The greatest expenditure of resources for this study went into the production of the films. It is hoped that these films can be used in the future for more comprehensive testing of the Thought Model method than was possible in this case. For instance, the population from which students were drawn was not large enough, nor was there sufficient collateral information about the students, to insure that students would be assigned to different sections on a random basis. Engineering aptitude test scores and previous semester's grade point averages were available, but there is little reason to assume that either can be correlated with visualization aptitude. Therefore, no attempt was made to match sections on the basis of these scores or grade point averages. The difficulty of the subject matter on which the students were tested also makes it virtually impossible to obtain a meaningful measure of the performance of uninstructed students as a control group. One-sixth of all students tested in this study had mean scores of 30.0 or less. It does not seem likely that testing students with neither previous experience nor instruction in engineering graphics would provide a useful base score for comparison purposes.

There is a wide range of student performance among students at different schools. This can be attributed to differences in admission procedures. State Colleges in California require that entering students come from the upper one-third of their high school graduating class. The Junior Colleges are not able to impose any such restriction. The variation among teachers is a more serious limitation on the conclusions to be drawn from a study such as this. An analysis of the interactions among such variables by analysis of variance techniques could provide some measure of otherwise uncontrolled variables. In this case the size of the sample and the scope of such an exploratory study made it seem unlikely that such an analysis would be very fruitful. However, in any future and large scale test made of the Thought Model method and the accompanying films it would be advisable to attempt more sophisticated measurement of the teacher variable.

Obviously the enthusiasm and experience of any teacher for any method can vary considerably. For this reason instructors were urged to use different methods if they taught more than one section. In the case of instructors A,C,D,E, and J this was done. Instructor D was the only one to use all three methods, and a comparison of his results is interesting for that reason. However, the size of the sample prevents attaching any great significance to this comparison. But it should be noted that his results are consistent with the overall results.

	Live		Film		Conventional	
	no.of students	mean	no.of students	mean	no.of students	mean
Instructor D	17	51.96	23	45.34	17	45.47
			22	39.49		

Tempering our conclusions, then, with awareness that more pre-

cise measurement of certain variables would be desirable, it is still reasonable to infer that the Thought Model method brings about a significant improvement in student performance when taught "live". But it does not show a significant difference from conventional methods when taught by film. This inference is also supported by the comparison shown in Table IV. In this case the performance of students in the investigator's class is compared to the performance of students who received the same instruction from the film of the investigator. Again, small samples prevent attaching too great a weight to this evidence, however, students receiving "live" instruction did considerably better than those viewing the investigator on film.

Comparing Live with Conventional does not compare the Thought Model method with any single conventional method since Conventional here represents a compilation of results from a number of teachers using methods familiar to them. The methods grouped together as Conventional probably differ considerably among themselves. In some cases the comparison of the two methods means that a new method in which the instructor has little experience is being compared with a method in which the instructor is practiced and proficient.

In a study such as this the effect of a single instructor can be considerable. For example, Instructor H has used the Thought Model method in the past and is enthusiastic about it. Instructur I at the same school had not used the method before. When Instructor I's class is not considered in the analysis of the overall results the difference between Live and Film is significant at the .001 level (rather than the .01 level) and the difference between Live and Conventional is significant at the .01 level (rather than the .05 level).

The results of this study indicate a desirable change in student performance can be brought about by the use of the Thought Model method in the teaching of the fundamental principles of orthogonal projection and their application to the solution of space problems. This is said while recognizing that variation in instructor aptitude and enthusiasm may have accounted for some part of the observed differences in student performance. While student assignment to different sections could not be accomplished on a matching basis, it is fair to assume that regular enrollment procedures result in a distribution of student talent not seriously different from normal distribution. Again, in a large scale testing program using the films and analysis of variance techniques it would be desirable to measure student variation. However, measurement of this variable does not appear to be as crucial as the teacher variable.

Conclusions

1. The Thought Model method can be learned and used effectively by teachers of engineering graphics to bring about significant improvement in classroom performance.
2. There is strong indication that such "teaching of teachers" can be done by film.
3. The film cannot replace the live classroom instructor. The use of the films in teaching students is not as effective as the use of the film in teaching teachers. However, there is no reason to believe that the films would not be a useful supplementary device to an instructor presenting the Thought Model method to his students.

Recommendations

1. Since the Thought Model method requires no special equipment and it can be learned by studying the films with a minimum of personal instruction, there is good reason to expect that the widespread distribution of the films offers an economic method of achieving significant improvement in the teaching and learning of the fundamental principles of orthogonal projection and their application to the solution of space problems.
2. The films should be made available generally to teachers of engineering graphics. (See Appendix B for reactions from engineering graphics instructors).

APPENDIX

GRADING SYSTEM

TEST 1

Problem 1 - 30 points
" 2 - 30 "
" 3 40 "

No partial credit.

TEST 2

Problem 1 - 20 points
" 2 - 20 "
" 3 - 30 "
" 4 - 30 "

No partial credit.

TEST 3

Problem 1 - 20 points
" 2 - 30 "
" 3 - 50 "

No partial credit for Prob. 1 and 2

Prob. 3 -
- 10 points for T.L. identification.
- 20 " " H - view of line AB.
- 20 " "location of intersection of planes 1 and 2.

TEST 4

Problem 1 - 25 points
Problem 2 - 35 "
Problem 3 - 40 "

No partial credit.

TEST 5

Problem 1 - 15 points
Problem 2 - 25 "
Problem 3 - 25 "
Problem 4 - 35 "

No partial credit for Probs. 1, 2, and 3.

Prob. 4 - (a) For finding true shape of surface ABC - 15 points.
(b) For complete solution, 20 points additional.

TEST 6

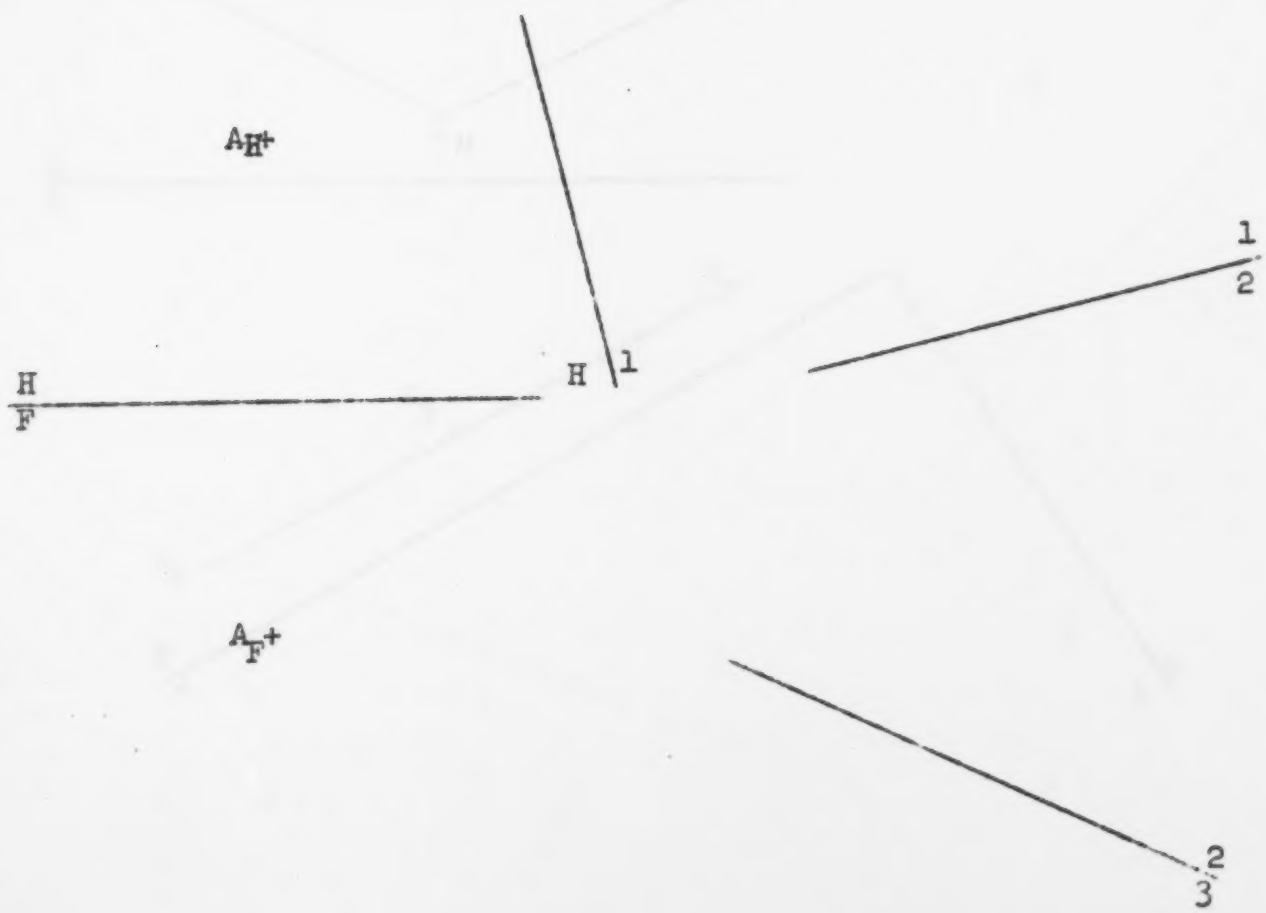
Problem 1 - 15 points
Problem 2 - 15 "
Problem 3 - 20 "
Problem 4 - 15 "
Problem 5 - 15 "
Problem 6 - 20 "

No partial credit.

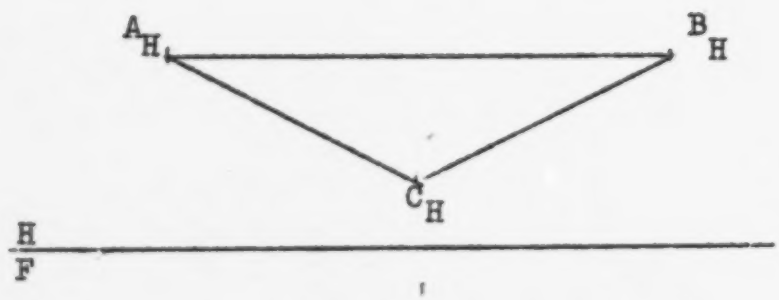
University of California
Department of Mechanical Engineering
and
Engineering and Sciences Extension
THOUGHT MODEL STUDY
A.S. Levens, Investigator

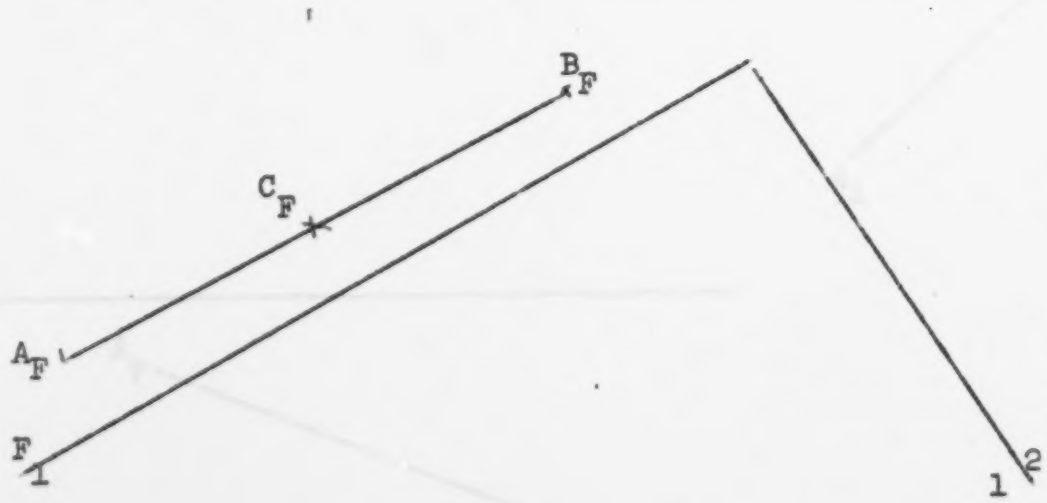
Test 1

1. Determine the views of point A on planes 1, 2, and 3.

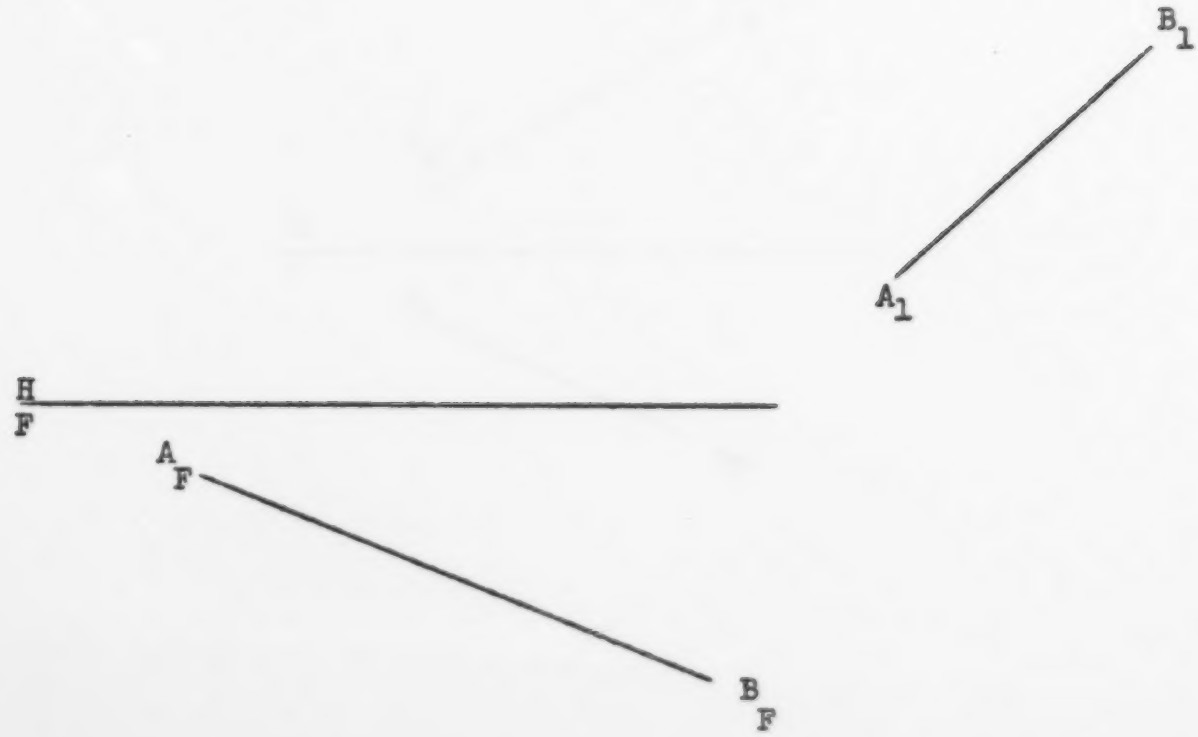


2. Locate the views of triangle ABC on planes 1 and 2.





3. Locate the H view of line segment AB.



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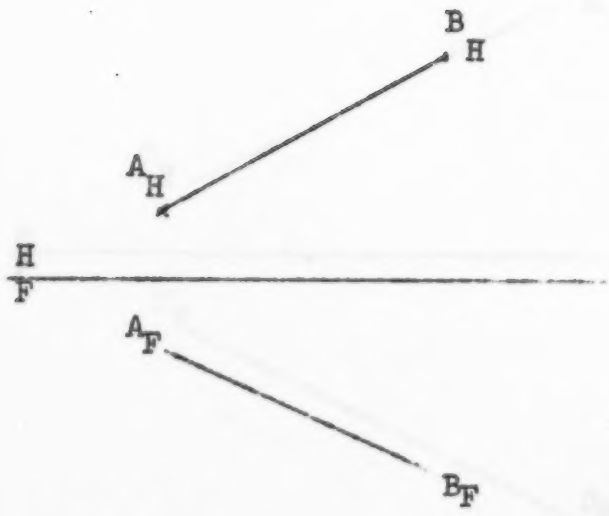
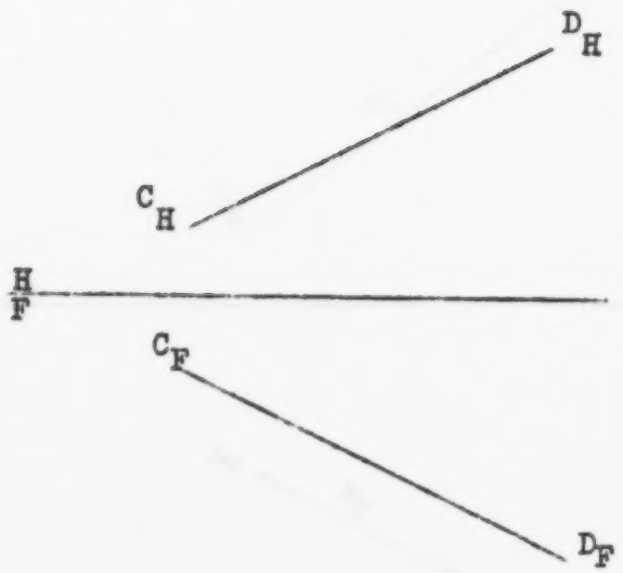
Test 2

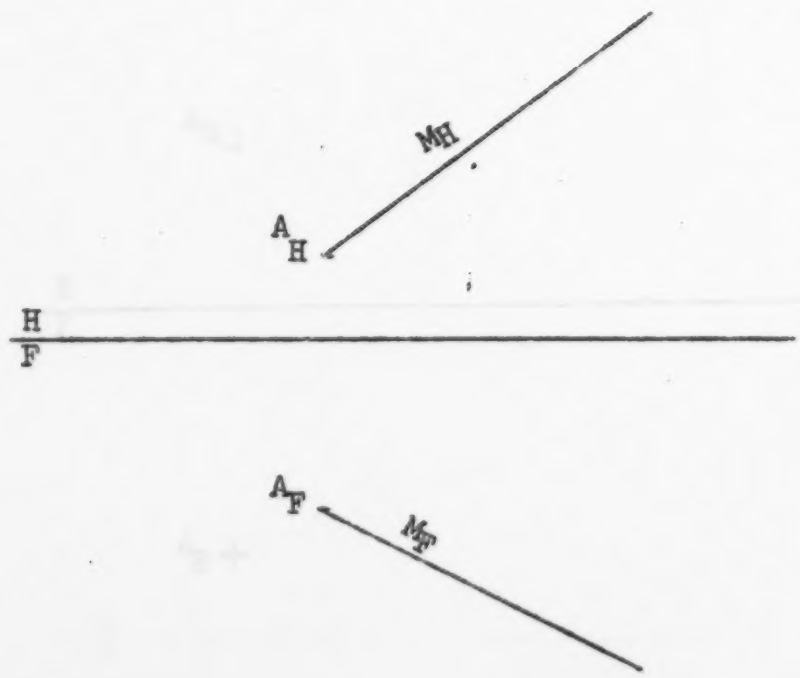
1. Determine the true length of line segment AB. Use a supplementary view.



2. Determine the true length of line segment C D. Use the method of rotation.



3. Line segment AB, which lies on line M, is 2 inches long. Determine the location of the H and F views of point B.



4. Line segment AB is 2 inches long and is parallel to the F plane. Point B is in the H plane and to the right of point A. Locate the H & F views of point B.

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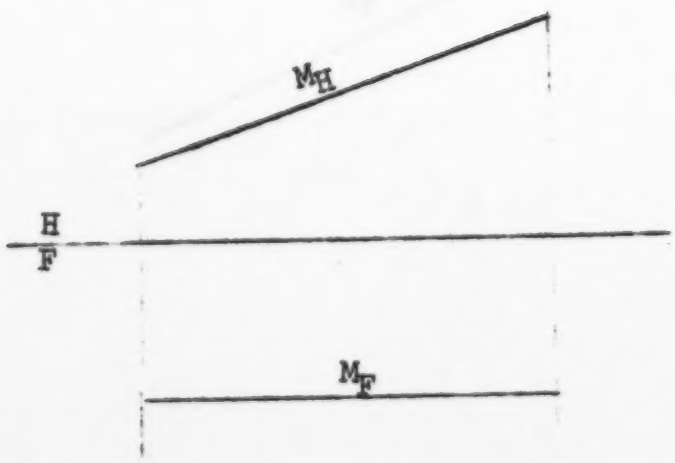
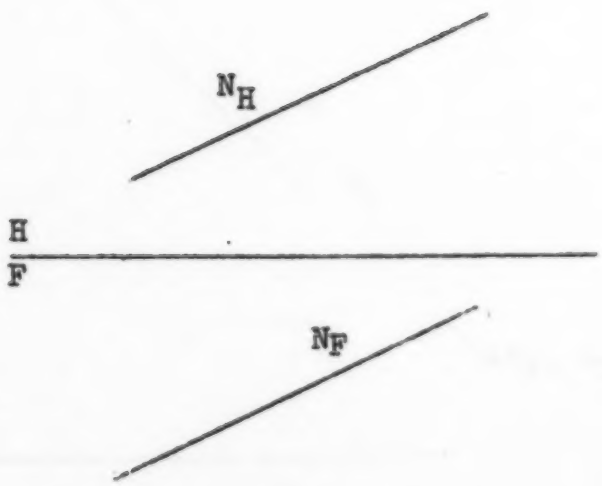
Test 3

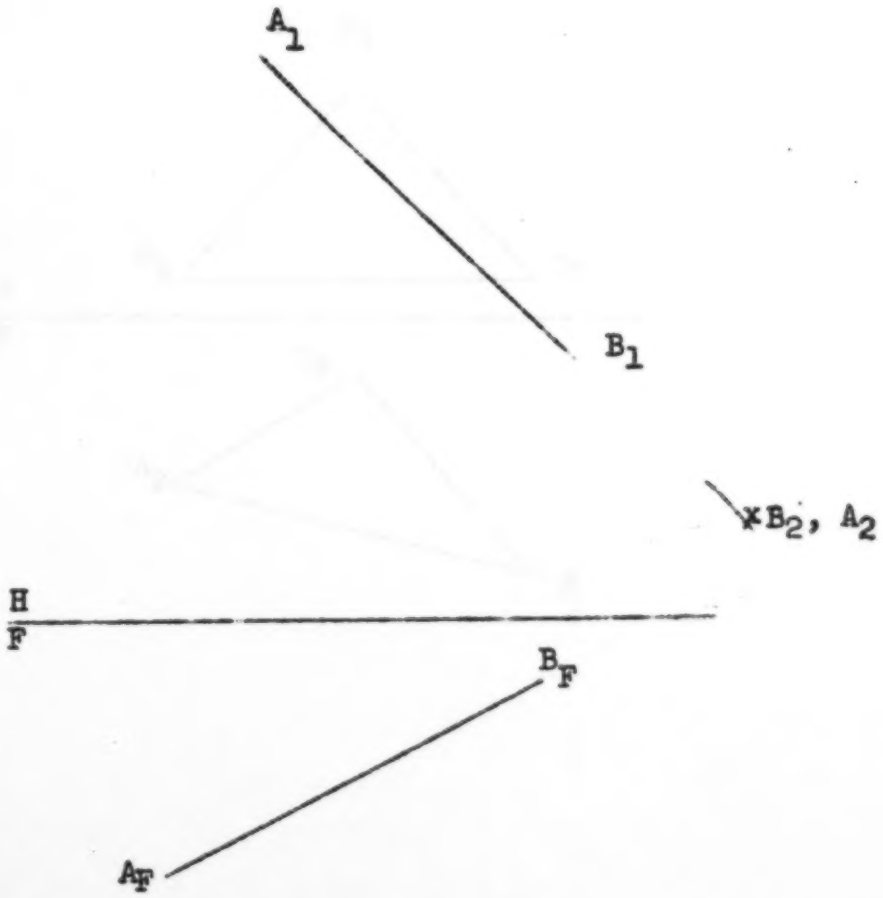
1. Determine the point view of line "M".



2. Determine the point of view in line "N".



3. Locate the H view of line AB. Label the true length view, T.L. Also locate the line of intersection of supplementary planes 1 and 2.



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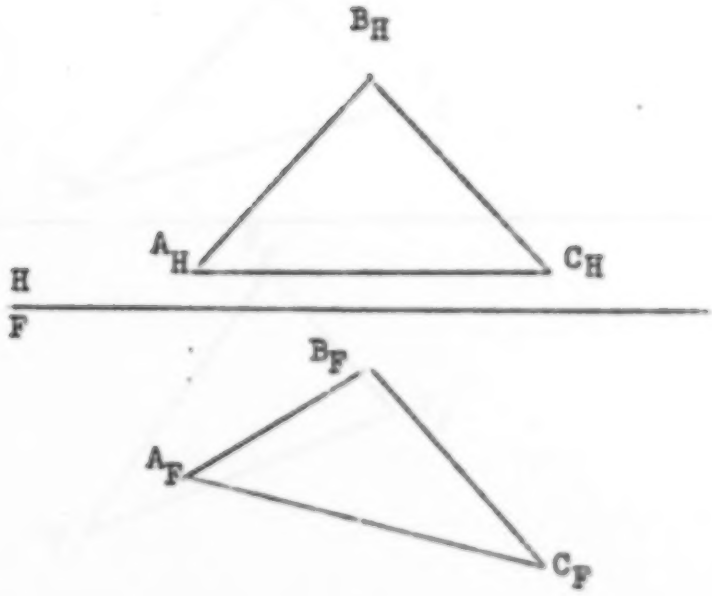
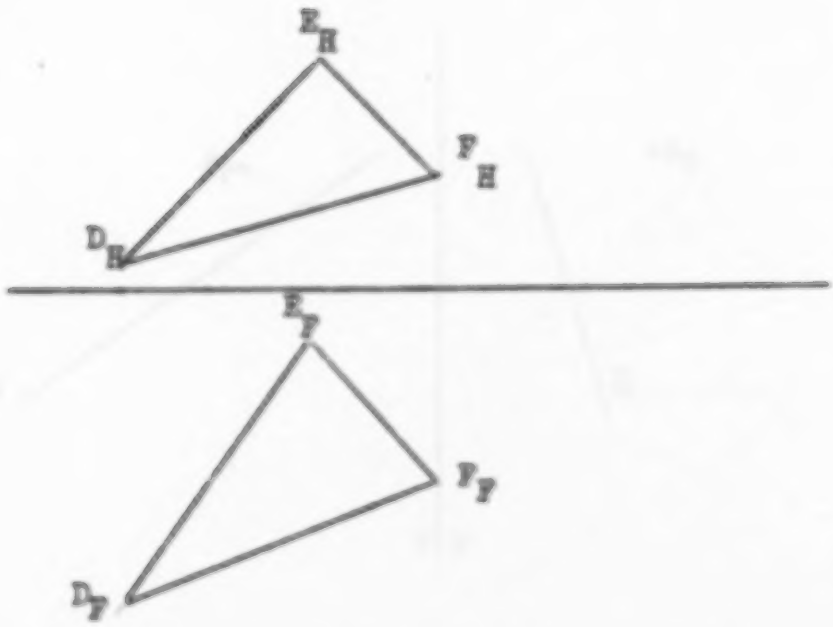
Test 4

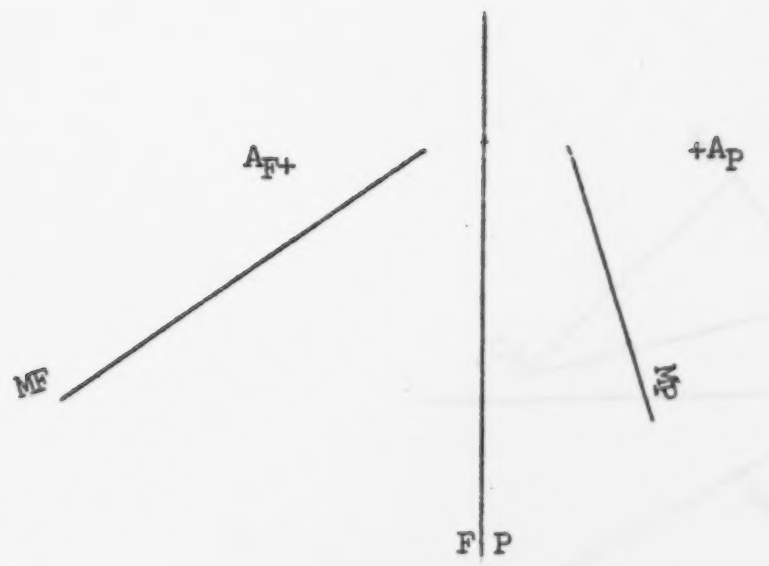
1. Determine the edge view of plane ABC.



2. Determine the edge view of plane DEF.



3. Determine the edge view of the plane determined by point A and line "M".



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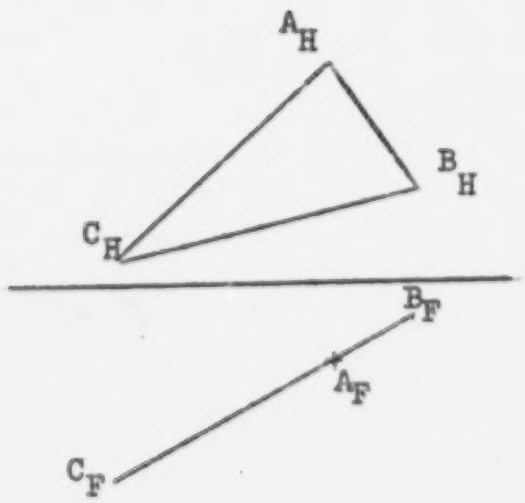
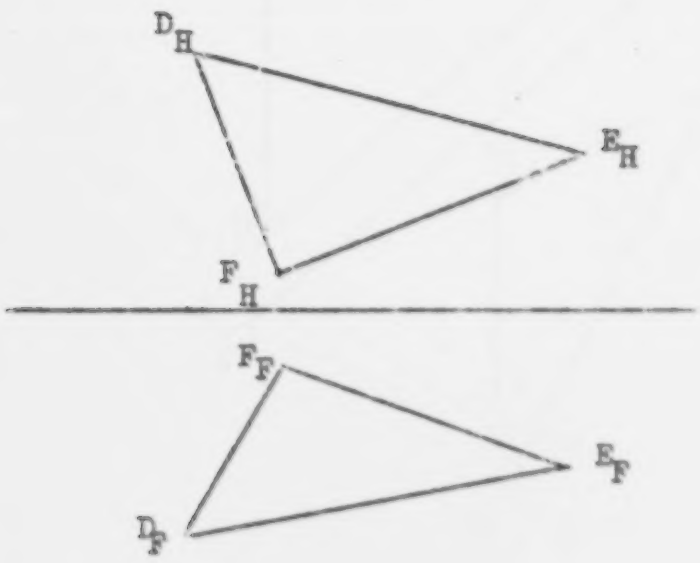
Test 5

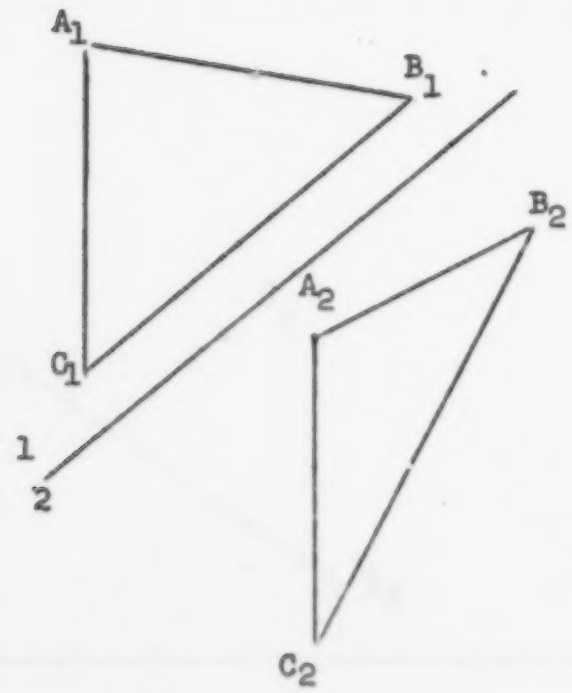
1. Determine the true shape of surface ABC.



2. Determine the true shape of surface DEF.



3. Find the true shape of surface ABC.



4. Equilateral triangle ABD lies in the plane of point C and line AB. Locate the H & F views of the triangle ABD.

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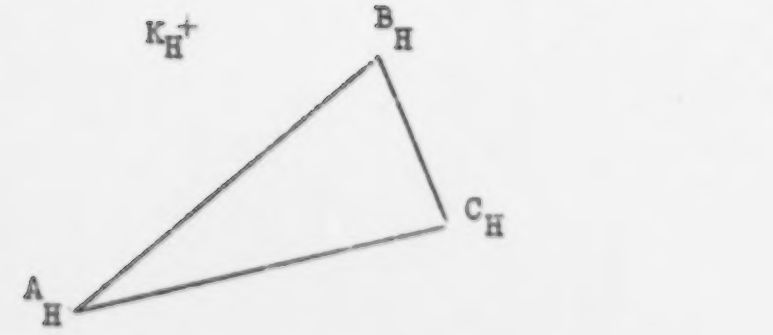
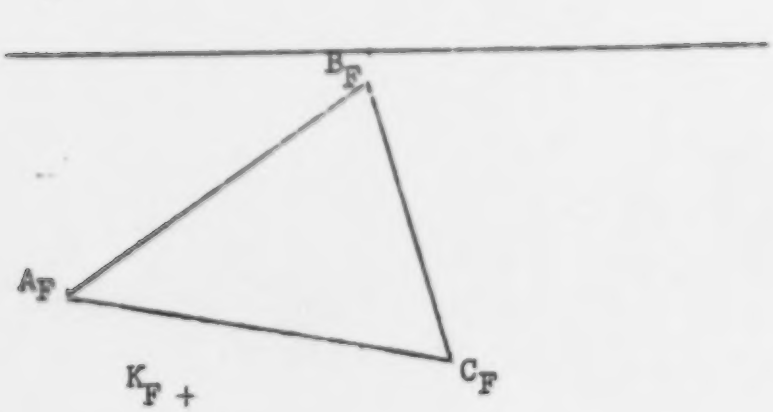
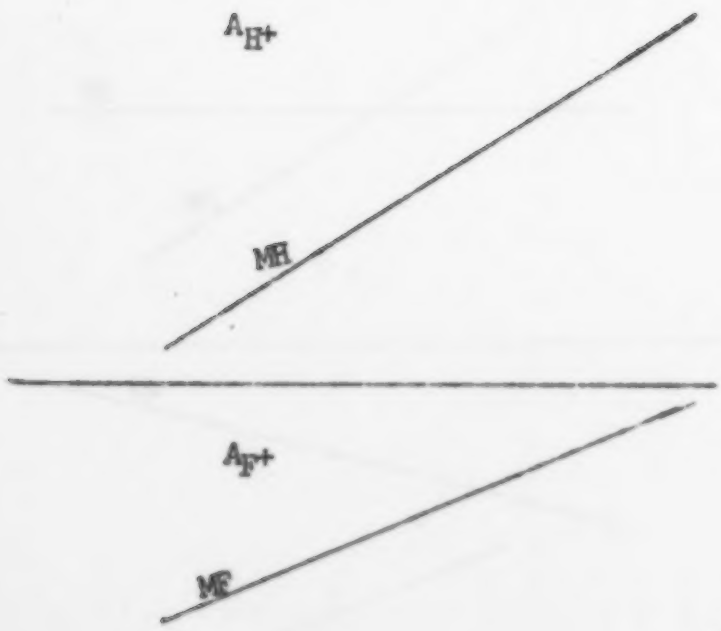
Test 6

1. Determine the perpendicular distance from point K to plane ABC.

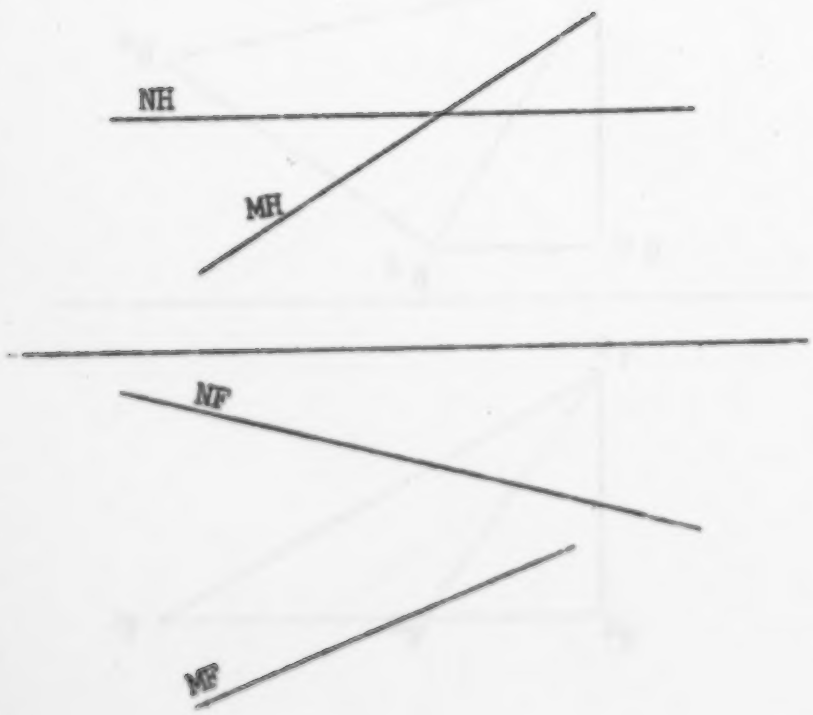




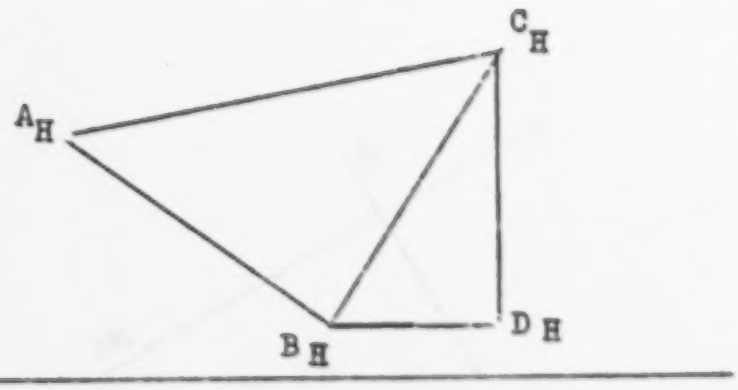
2. Determine the H & F views of the perpendicular from point A to line "M".

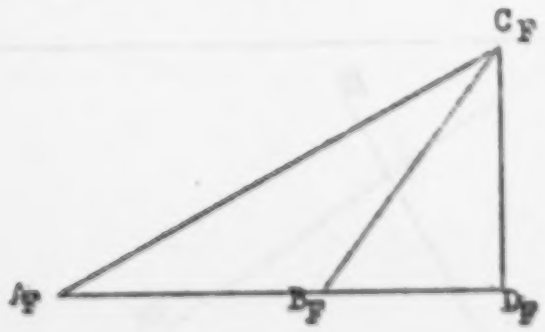


3. Determine the H. & F views of the common perpendicular between lines "M" and "N".

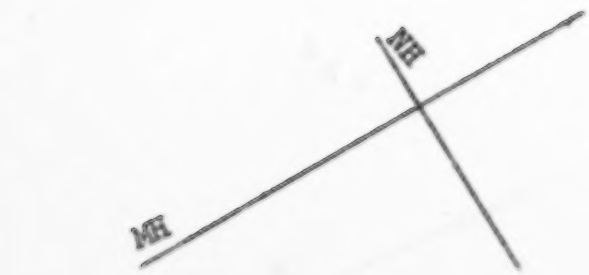


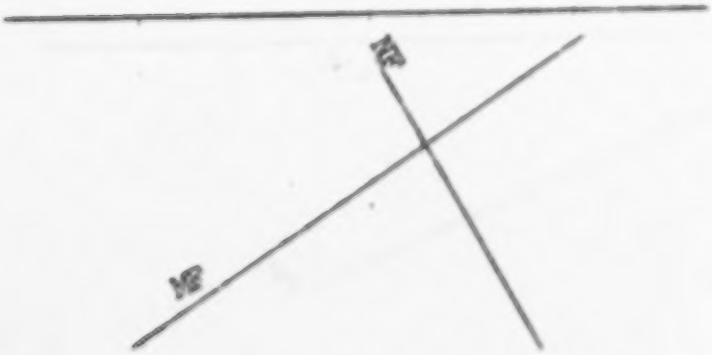
4. Determine the angle between planes ABC and BCD.





5. Determine the angle between lines "M" and "N".





6. Determine the H & F views of line AD which makes an angle of 60° with line AC. Point D is on line BC.

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